

Fleming and the Thermionic Valve

Professor Sir John Ambrose Fleming was the father of electronics, the birth of which took place at University College London in 1904 when he invented the thermionic valve. Although this was his major claim to fame, Fleming also made other important contributions to, for example, photometry, radio and electric measurements, and wireless telegraphy. Many students of electrical engineering will be familiar with his left and right hand rules devised to assist remembering the relative directions of field, current and force for electric motors and generators.

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Introduction

John Ambrose Fleming (Figure 1) was the eldest son of seven children and born in Lancaster on 29th November 1849. His father was a Congregational minister who later moved to London to take charge of the Kentish Town Congregational Chapel. Fleming showed early signs of prodigy, building his own camera and experimenting with electricity and magnetism. He delivered his first lecture on electromagnetic phenomena at the age of thirteen and a year later was sent to University College School, on London's Gower Street, where he matriculated at the age of sixteen. He then enrolled into University College London (UCL) to study for a Bachelor of Science (BSc) degree. However, after two years he was forced to leave the college due to a shortage of money and took a job with a shipbuilder in Dublin. But he found the work so boring that he returned to London after two months and found work as a clerk on the Stock Exchange. During this time he completed his degree through evening study and graduated with a first class degree in 1870.

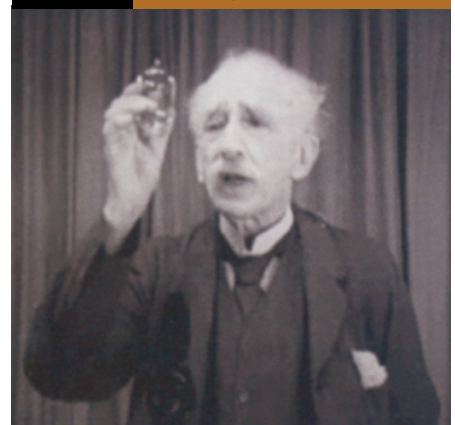
In order to accumulate enough funds to continue his studies, Fleming took a position as science master at Rossall College, a boys' public school near Blackpool. After 18 months he returned to London to study chemistry at the Royal College of Science (now Imperial College) where he also met Sir Oliver Lodge who became a life-long friend. He had to take up a daytime teaching job to finance himself, but he gained a first class degree. It was here that his studies of the voltaic battery

led to his first scientific paper 'On the New Contact Theory of the Galvanic Cell', which was the first paper to be read to the new Physical Society of London (now the Institute of Physics). It appears on page 1 of volume 1 of their proceedings.

Financial constraints again forced him to take up teaching work and in 1874 he became science master at Cheltenham College, a public school, earning £400 per year. He continued his scientific research and corresponded with James Clerk Maxwell at Cambridge University, eventually winning a scholarship to St John's College, Cambridge to study at the Cavendish laboratories under Maxwell, sometimes being the only student at Maxwell's highly complicated lectures. In due course, Fleming graduated with a first in chemistry and physics and went on to obtain the degree of Doctor of Science from the University of London on the subject of 'Electricity Treated Experimentally'. He became a Fellow of St John's College in 1882.

Fleming served one year as a demonstrator of mechanical engineering at Cambridge before being appointed, in 1881, to the Professorship of Physics and Mathematics at the newly formed University College, Nottingham. But after less than one year he left. His cousin, a Mr Arnold White, was secretary to the Edison Telephone Company, and, through him, Fleming obtained the post of consultant. He took an active role in the litigation that followed the extension of the Post Office monopoly from telegraphs to telephones. White was also the

Figure 1 Prof. Sir John Ambrose Fleming



The Author: Professor Keith Ward is with University College London.

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secretary of the Edison Electric Light Company and Fleming became their 'Electrician'. This enabled him to visit America and meet Edison.

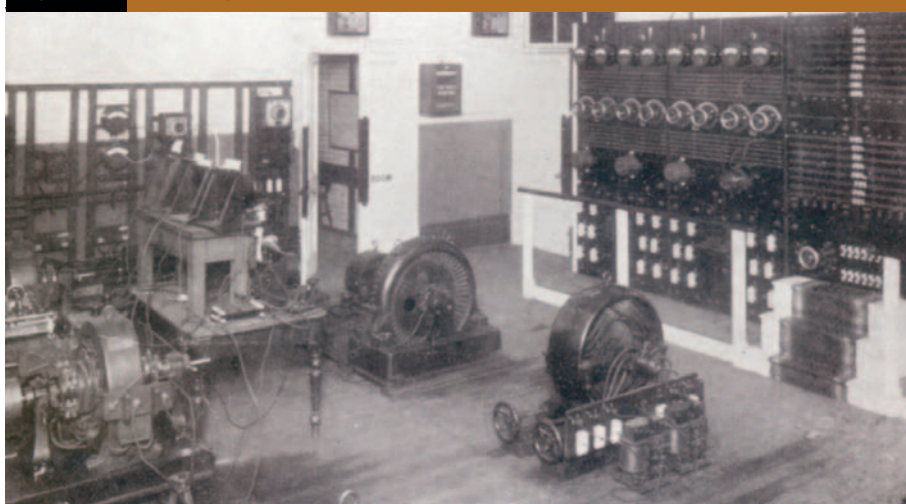
Chair at UCL

Fleming's reputation became such that he was invited to give a series of lectures at UCL, the premier college of London University. A year later, in 1884, he was invited by UCL to set up a new department and occupy its Chair of Electrical Technology (later Engineering). This was the beginning of a 42-year tenure of the chair and it was the first engineering department in the country, reflecting the forward thinking of this world-renowned university. At last he was back in London with a post that suited his many and varied talents and his light teaching duties allowed him plenty of time for research and consultancy. On his appointment to UCL the only equipment he had was 'a blackboard and a piece of chalk' but he persuaded the university to give him a £150 grant and a small room. But by 1896 he had managed to accumulate £5000 to establish a laboratory (Figure 2). He devoted his time to a wide variety of aspects including transformer tests (acting as a consultant to Ferranti), standards and measurements, incandescent lamps and photometry, low temperature effects on electrical resistance (with Sir James Dewar), a.c. machines, and thermionics. As a lecturer he gave meticulously prepared presentations, but spoke very fast so that it was difficult for students to take notes.

Research into Thermionics

Fleming's research into thermionics began when employed by the Edison Company. A long-term problem with incandescent lamps was the blackening of the inside surface of the glass envelope during their operation and the fact that the carbon filament broke at the slightest shock. Edison performed experiments by positioning a metal plate

Figure 2 Fleming's laboratory at UCL



between the filament and envelope to minimise the darkening. In the course of this work he noticed that a small current flowed if the plate was connected to the positive terminal of the filament supply but there was no current if it was connected to the negative terminal. Edison saw no special value in the effect, but as was his habit with his discoveries, he applied for a patent anyway. Others also studied this, so-called, 'Edison Effect', including Fleming who, in 1883, noticed that in many burnt-out lamps there was a clean line on the glass in the plane of the hairpin-shaped carbon filament and on the side of the loop opposite to the burnt-out point of the filament. He deduced that '... the unbroken part of the filament acted as a screen to the line of clear glass and that the discharge from the overheated point on the filament bombarded the remainder of the bulb with molecules of carbon or vaporised metal shot out in straight lines.' In 1888, he conducted further research by using a variety of metal plates and cylinders, the positioning of which could vary the amount of, and even stop, the particle emission. He also found that he could use the modified lamp to rectify alternating currents over a wide range of frequencies. He presented a paper on his research to the Royal Society and was elected as a Fellow as a result. But he was very busy and did not appreciate the potential applications of his research into the 'Edison Effect'.

Fleming's association with the development of radio communications, leading to his famous invention of the valve, came from the arrival in England of Guglielmo Marconi in 1896. Fleming experienced the power of wireless in 1898 while on holiday in Bournemouth when he was astonished to receive a Morse Code message 'Compliments to Professor Fleming' which had been transmitted over 12 miles of sea. A year later he was engaged to become Scientific Advisor to the Marconi

Company at a fee of £300 per annum.

Fleming's first job was to design a power plant sufficiently large to transmit a signal across the Atlantic. The plant comprised a 32-horsepower engine driving an alternator, which with two transformers was capable of generating 20 000 volts. It included a new type of high-capacity condenser developed by Fleming who also designed the transmitter (Figure 3). After more than a year of research in the UCL laboratory and experiments at the transmitter site at Poldhu, in Cornwall (Figure 4), full tests commenced in July 1901 and in December the transatlantic transmission was attempted. On 11 December bad weather

Figure 3 Fleming's transmitter

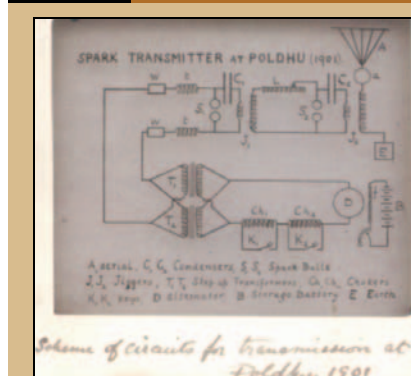


Figure 4 Poldhu aerial



prevented reception, but on the following day at 12.30 pm, 1.10 pm and again at 2.20 pm the Morse Code message 'SSS' was successfully received and history was made.

There was some controversy about the wavelength of the first transmission, and in 1935 Fleming was asked to clarify this issue and replied:

The wavelength of the electric waves sent out from Poldhu Marconi station in 1901 was not measured because I did not invent my cymometer or wavemeter until October, 1904. The height of the original aerial (1901) was 200 feet, but then there was the coil of a transformer, or 'jiggeroo' as we called it, in series with it. My estimate was that the original wavelength must have been not less than about 3000 feet, but it was considerably lengthened later on. I knew at that time that the diffraction or bending of the waves around the earth would be increased by increasing the wavelength and after the first success I was continually urging Marconi to lengthen the wavelength, and that was done when commercial transmission began. I remember I designed special cymometers to measure up to 20 000 feet or so.

One of the problems with Marconi's first system was the lack of reliability and sensitivity of the receiver. The device was called a coherer (Figure 5, left) because it comprised a small tube of metal filings that would conduct (or cohere) when excited by a radio wave. A clockwork 'tapper' was used to tap the tube to break-up the filings between symbols. Fleming, among others, sought ways to improve this device. He tried

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to develop chemical rectifiers, until one day in October 1904 he had what he later described as a 'sudden very happy thought – why not try the lamps'. He instructed G B Dyke, his assistant at UCL, to set up an experiment comprising an oscillatory circuit, with two Leyden jars, a wired wooden frame and an induction coil. Another circuit had one of his lamps and a galvanometer. Both circuits were tuned to the same frequency. Later when recalling this experiment, he said:

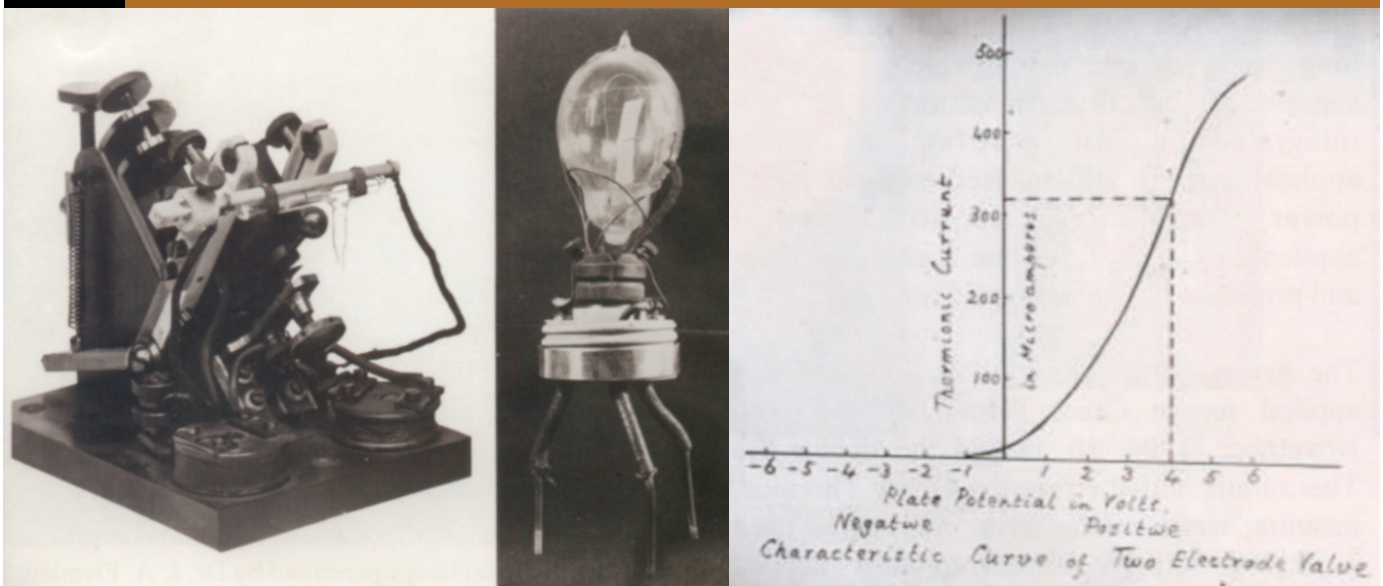
It was about 5 o'clock in the evening when the apparatus was completed. I was, of course, most anxious to test it without further loss of time. We set the two circuits some distance apart in the laboratory, and I started the oscillations in the primary circuit. To my delight I saw that the needle of the galvanometer indicated a steady direct current passing through, and found that we had had in this peculiar kind of electric lamp a solution of the problem of rectifying high-frequency wireless currents. The missing link in wireless was 'found' and it was an electric lamp! I saw at once that the metal plate should be replaced by a metal cylinder enclosing the whole filament, so as to collect all the electrons projected from it. I accordingly

had many carbon filament lamps made with metal cylinders and used them for rectifying the high-frequency currents of wireless telegraphy. This instrument I named an oscillation valve. It was at once found to be of value in wireless telegraphy, the mirror galvanometer that I used being replaced by an ordinary telephone, a replacement that could be made with advantage in those days when the spark system of wireless telegraphy was employed. In this form my valve was somewhat extensively used by Marconi's Telegraph Company as a detector of wireless waves. I applied for a patent in Great Britain on November 16, 1904.

Fleming called it a valve (Figure 5, centre) because it operated like a water valve allowing flow only in one direction. But it became known as a diode, from the Greek *di* meaning two, relating to the two electrodes in the device. The family of devices spawned from Fleming's invention became known as thermionic valves (from the Greek *thermos*, meaning warm), but in the USA the term became 'vacuum tube'.

In a letter to Marconi about his discovery, Fleming wrote, almost as an after-thought, 'I have not mentioned this to anyone yet as it may become very useful.' In

Figure 5 Fleming's first thermionic valve and the coherer



less than two years, H H Dunwoody, who worked for the De Forest Wireless Co, developed the crystal detector (sometimes known as a 'cat's whisker'). It was a crude semiconductor device comprising a thin wire, the point of which made contact with a piece of material (even coal) to produce a point contact rectifier, which was cheaper and more convenient than the diode. This was part of Dr Lee de Forest's strategy to challenge Marconi's dominance of the wireless market. In 1905, de Forest patented a two-electrode valve with a double battery, instead of Fleming's single battery. He called it an 'audion' and it sparked off a bitter row between de Forest and Fleming who claimed his idea had been plagiarised. A year later, de Forest added a 'grid' between the filament and the plate to create the triode, but he still called it an audion and used it as a rectifier; it took another four years before it was used as an amplifier. The result was a prolonged legal battle between Fleming and the Marconi company versus de Forest that would run for decades. Fleming did not claim credit for the introduction of the grid but did contest the patent infringement of the thermionic technology. De Forest contended that what Fleming claimed as an invention was already inherent in Edison's patent of 1883. It was not until 1916 that a US court ruled that Marconi had infringed the de Forest patent and also de Forest had infringed Fleming's patent. But in 1943, the US Supreme Court ruled that Fleming's patent was 'rendered invalid by an improper disclaimer'.

In Retirement

Fleming retired from UCL in 1926 at the age of 77 and moved to the seaside town of Sidmouth in Devon where he lived with his second wife, whom he married in 1933 (his first wife had died in 1917), and two of his sisters. During his retirement he still took an active interest in electronics. He retained his consultancy position with Marconi almost up to the time of his death in 1945, and was also president of the Television Society for 15 years, often travelling to London for their meetings. But he also had many interests in addition to his work. He was a keen photographer, painted watercolours, loved walking and was a devout Christian who did not believe in Darwinism, and who preached at various churches, including London's St Martins in the Field. He bequeathed much of his estate to Christian charities, especially those that helped the poor.

Publications and Awards

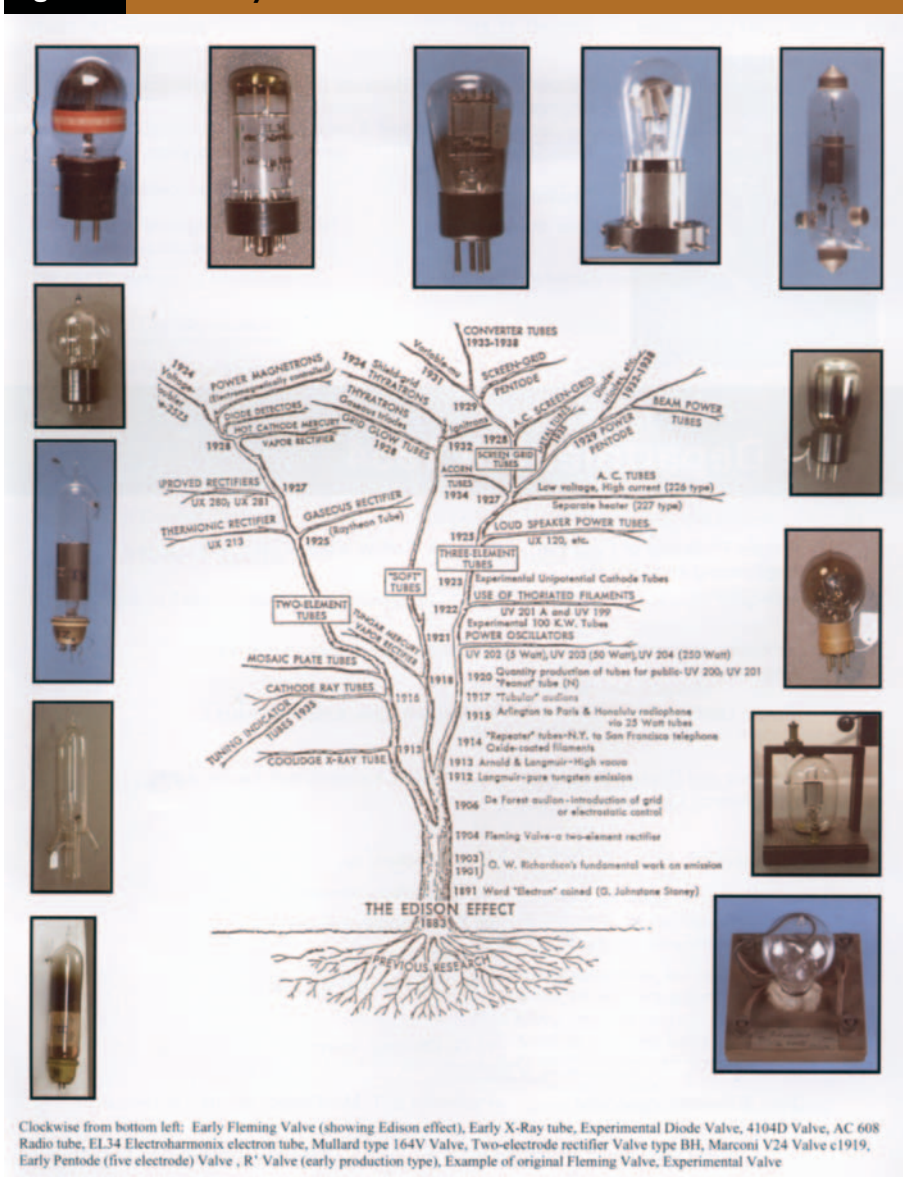
During his distinguished career, Fleming was the author of more than 100 scientific papers and books, the most significant being *The Alternating Current Transformer* (1889, 1892), *The Principles of Electric Wave Telegraphy* (1906), *The Propagation of Electric Currents in Telephone and Telegraph Conductors* (1911) and *Memoirs of a Scientific Life* (1934). His honours were many and included the Hughes Medal of the Royal Society (1910), the Albert Medal of the Royal Society of Arts (1921), the Faraday Medal of the IEE (1928), the Duddell Medal of the Physical Society of London (1931), the Radio Medal USA (1933), the Franklin Medal USA (1935), and the Kelvin Medal by the three Engineering Institutions of Great Britain (1935). In 1929 he was knighted for his valuable service in science and industry.

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However, he will be remembered for his invention of the valve, which heralded the birth of the electronics era. The developments of valve technology were many and varied (Figure 6 – source: Maclaurin, 1949, p.91) until overtaken by

Figure 6 The family tree of the thermionic tubes



the semiconductor age. But they are still used for applications such as power stages of radio and television transmitters, in audio amplifiers, as detectors of optical and short wave radiation, and in sensitive equipment that must be 'radiation hard'.

Bibliography

UCL Fleming Valve Centenary Celebration – <http://www.ee.ucl.ac.uk/dept/history/fleming/>

Institute of Chemistry, Jerusalem – <http://chemistry.huji.ac.il/~eugeniik/history/fleming.htm>

The National Valve Museum – <http://www.r-type.org/ststic/pioneer.htm>

Atherton, W. A. *Wireless World*, August 1990 issue.

Radio Electronics – http://www.radio-electronics.com/info/radio_history/gtnames/fleming.php

University of Huston – <http://www.uh.edu/engines/epi1323.htm>

Biography



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Professor Keith Ward joined British Telecom (BT) in 1948 as an engineering apprentice. In 1982 he became Chief Engineer responsible for planning BT's trunk telephone network together with the development, procurement and installation of switching and transmission equipment. He subsequently assumed a similar responsibility for the whole of BT's inland network. His final job with BT was to design, launch (in 1990) and run the BT Telecommunications Masters Programme, validated by the University College London (UCL) for the award, to successful delegates, of an MSc in Telecommunications Business. On retirement from BT in 1992 he became Visiting Professor of Telecommunications Business at UCL where he continued to run the BT Masters Programme as well as lecturing on other graduate and post-graduate courses, but his commitments are now only part-time. He is an honorary member of IBTE (now TCN) and a member of the editorial board of its journal. He was the chairman of the London section of the IPOEE and had editorial responsibility for the Structured Information Programme supplement to the IBTE journal. He is a Chartered Engineer and Fellow of the Institution of Electrical Engineers. He is also a Fellow of the City and Guilds of London Institute and Member of the Chartered Management Institute.

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